KamLAND Front-End Electronics

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The primary KamLAND front-end electronics (KAMFEE) were developed at LBNL specifically for the KamLAND experiment. These electronics were designed to meet the following experimental requirements: timing better than that of the PMT's, minimal system and channel deadtimes, multiple hit and pileup resolution capability, large dynamic range, and high single photoelectron detection efficiency.

The KAMFEE system is based on an innovative Application Specific Integrated Circuit (ASIC) developed at LBNL, the Analog Transient Waveform Digitizer (ATWD). The ATWD simultaneously can capture four channels of independent signals at sample speeds from 200 MHz to over one GHz. The sampling action is generated internally without the need for high-speed external clocks. The use of the ATWD permits extremely high sampling speeds while allowing the a conservative KAMFEE board-level clock frequency of 40 MHz. The ATWD is equipped with a common-ramp parallel Wilkinson 10-bit ADC, permitting the direct conversion on-chip of the captured analog signal. Digitization and readout of the entire 128-sample waveform requires about 27 microseconds at 40 MHz for the 10-bit range.

The KAMFEE design includes 12 electronics channels per board. We use 198 boards to instrument all 2,126 KamLAND PMT's, including both the the inner and outer detectors. The board circuitry for each channel includes two ATWD chips, which alternately acquire waveforms in a ping-pong arrangement. This setup minimizes single-channel electronic deadtime, as the second ATWD can acquire data if a pulse arrives which the first ATWD is digitizing. This is a very important feature, as KamLAND PMT pulse rates are quite high - 50 KHz for the 17-inch PMT's.

The multiple input channels to each ATWD are used to acquire the same waveforms at different gains. This gives the FEE boards a very large dynamic range, as the same waveform can be analyzed at a lower gain if it overflows the highest-gain channel. With this setup, we can accurately record waveforms which vary in size by over three orders of magnitude.

We run the ATWD's on each KAMFEE at a sampling rate of 0.63 GHz, an interval of 1.6 ns between samples. This sampling rate provides multiple samples on the leading edge of the PMT pulses, and it thus allows us to reconstruct pulse arrival times to sub-nanosecond accuracy. This timing is significantly better than the $\sim$3 ns transit-time spread of the fast 17-inch PMT's. By recording the full waveform for each pulse, the ATWD-based electronics give us the tools to resolve pileup and distinguish sequential pulses.

The KAMFEE design includes both analog and digital components on the same board. The analog and digital power and ground circuits are carefully separated so that digital noise will not be picked up by the discriminator circuits. We are thus able to operate with very low discriminator thresholds, typically 0.3 mV. At this low threshold, the discriminator efficiency for single photoelectrons is greater than 95%.

The first complete KAMFEE boards were delivered to LBNL in July 2001. Unfortunately, the boards were plagued with a high rate of component loading errors, and we were forced to undertake an extensive program of testing and repair. The first KAMFEE electronics were installed in KamLAND in September 2001. By November of that year we had sufficient working electronics for all the 17-inch ID PMT's and the OD, and we recorded out first muon events. In the initial operation of the experiment we had a high board failure rate, due primarily to unsoldered pins on the KAMFEE boards. We did not have a sufficient number of working boards to read out the 20-inch tubes until the summer of 2002.

After running KamLAND for several months we uncovered a small design flaw in the electronics: the AC-coupling effects of an input transformer for large pulses had been overlooked. This flaw meant that the electronics were effectively blind for $\sim$200 μs after high light level events such as muons. In a January 2003 upgrade, we repaired this flaw on all KAMFEE boards by removing the input transformer and making several other small adjustments. This upgrade was accomplished with a minimal amount of detector downtime, only 4 days.

The KAMFEE electronics are now running very stably - we have had no board failures in several months.

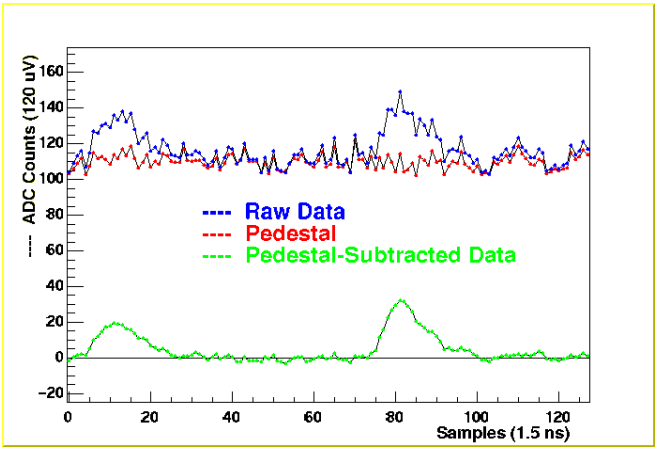

FIG. 1: A sample waveform from the KamLAND front-end electronics system.